

Neuromagnetic studies of visual and auditory infrequent target detection tasks

S. Iwaki¹, N. Hirata^{1,2}, M. Tonoike¹, and I. Kaetsu²

¹*Life Electronics Research Center, Electrotechnical Laboratory, 1-8-31 Midorigaoka, Ikeda, Osaka 563-8577, Japan;* ²*Department of Nuclear Engineering, Faculty of Science and Technology, Kinki University, 3-4-1 Kowakae, Higashi-Osaka 577-8502, Japan.*

1. Introduction

Many electrophysiological studies of infrequent target detection have been performed using ‘oddball’ paradigm in which subjects were required to detect and respond to infrequent target events embedded in a series of repetitive (frequent) events. The oddball tasks have been known to elicit prominent component of event-related potentials (ERPs) called P3, which occurs about 300 ms after the infrequent stimulus onset [1][2]. The P3 is thought to reflect attentional resource allocation when working memory [3] is engaged [4]. These components have been widely used to investigate cognitive brain responses related to novelty, uncertainty, attention, and memory [2], however, the specific brain regions involved in the generation of this component and the modality dependency of these generators were largely unknown. Recent functional magnetic resonance imaging (fMRI) studies have shown that there were multiple brain regions including frontal, parietal and temporal regions, which were either modality specific or modality independent, involved in the detection of infrequent stimuli [5][6][7]. Because these studies have visualized the brain activation in terms of hemodynamic changes during the task execution relative to the control condition, temporal resolution of the results could not exceed a few hundred milliseconds.

In the present study, to clarify the spatio-temporal characteristics and the modality specificity of the neural activities in the human brain related to the detection of infrequent target stimuli, which are presented to either visual or auditory sensory modality, neuromagnetic measurements were performed.

2. Methods

Three normal right-handed volunteers with no history of neurological disorders were participated in the study. The subjects were experienced in neuromagnetic studies and provided informed consent. Typical visual and auditory oddball tasks were performed in separate sessions of

neuromagnetic recording. Each session was repeated 10 times, respectively. For the visual oddball task, stimuli were presented for 100 ms by light emitting diode (LED), which flashes either in red (infrequent target: 20%) or in green (frequent non-target: 80%) in the randomized order, located in the left visual field and separated with a visual angle of 7.4 degrees from a fixation point in front of the subject. For the auditory oddball task, monaural 1000 Hz (infrequent target: 20%) or 2000 Hz (frequent non-target: 80%) tone bursts (100 ms duration, 5 ms rise/fall time) were presented to the subject’s left ear in the randomized order. Subject was instructed to lift his right index finger immediately after detecting the infrequent target stimulus in both visual and auditory oddball tasks.

Neuromagnetic signals were measured with a whole-cortex-type DC-SQUID system (Neuromag-122TM), which was located in a magnetically shielded, air-conditioned room. The stimulus-related epochs of 700 ms, including a 200 ms pre-stimulus baseline, were recorded with a pass-band of 0.03 – 100 Hz and a sampling rate of 498 Hz. Event-related magnetic fields to correctly identified infrequent target stimuli and frequent non-target stimuli were independently averaged for more than 50 epochs in both visual and auditory tasks. The epochs with a neuromagnetic signal change exceeding 1500 fT/cm were rejected from signal averaging.

Figure 1 shows the schematic illustration of the method to visualize significant differences of the neural activity between target and non-target conditions using MEG measurements. For both visual and auditory tasks, distributions of neural activities corresponding to the infrequent target stimuli and the frequent non-target stimuli were estimated within a latency range of 100 to 500 ms after the stimulus onset with a time interval of 10 ms using the linearly constrained minimum variance (LCMV) [8] spatial filtering algorithm [9]. In calculating the functional activation map using an LCMV spatial filter, the filter output power as a function of location is normalized by the estimated noise power to compensate the noise dominance at

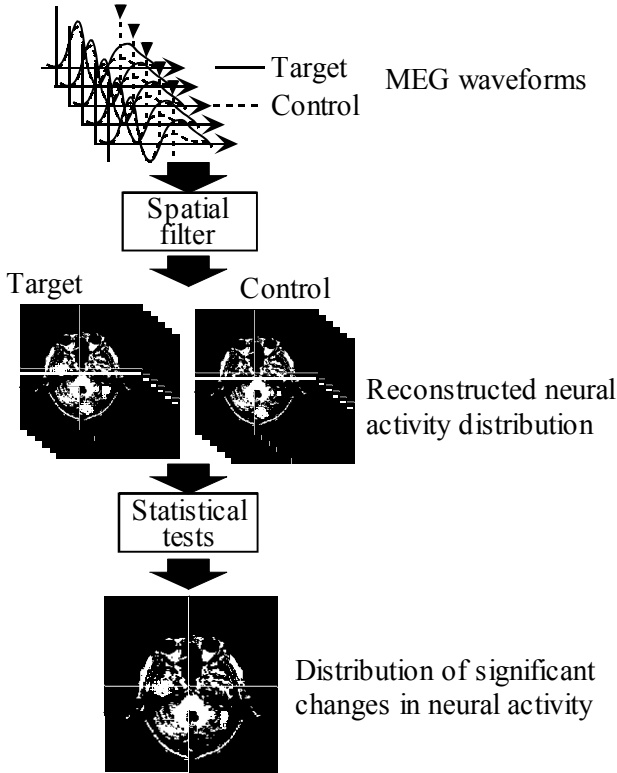


Figure 1: Schematic illustration of the method to visualize significant differences of the neural activity between target and control conditions using MEG measurements.

the locations where the sensitivity of the sensor array is low [9]. In this study, the noise power distribution was estimated from the pre-stimulus period of 200 ms. The spatial filter output was evaluated at 1190 points located on the uniform grid points with 10 mm spacing in each direction in the sphere head model. Voxel-by-voxel paired t-tests were used to detect statistically significant differences in the distributions of neural activation between the infrequent target and the frequent non-target conditions on each grid point at 10 ms interval using all 10 sessions in both visual and auditory tasks in each subjects.

3. Results

The percentages of errors in both visual and auditory task performances were less than 5% in all sessions. Mean reaction times (RTs) and standard deviations (SDs) for correctly identified targets were 352.8 ± 64.6 ms for visual task and 305.5 ± 71.2 ms for auditory task.

3.1 Visual task

Figure 2 shows the MEG waveforms for a typical subject. Figure 3 shows the regions where the

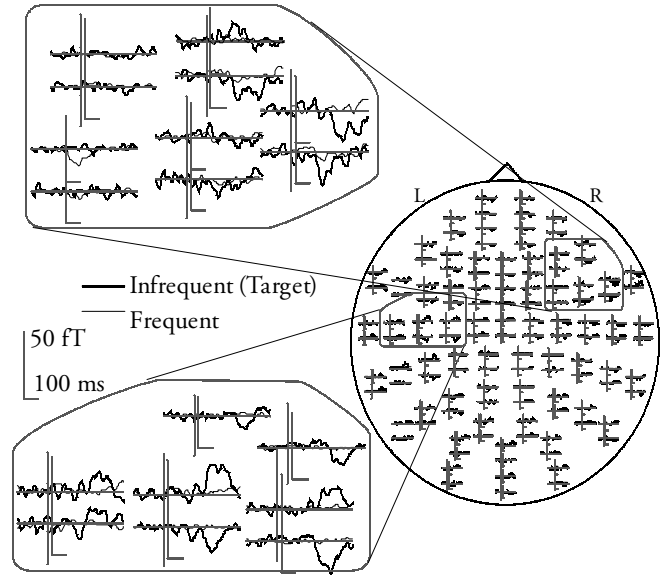


Figure 2: Example the MEG waveform measured during the visual task.

significant enhancement of the neural activity was detected in the infrequent target stimulus presentation compared to the frequent stimulus presentation during the visual task ($p < 0.0005$). Significant enhancement of the neural activity was detected in (a) the middle frontal or inferior frontal region (Brodmann's Area (BA) 44, 46) in the latency range between 260 and 310 ms, (b) the pre-central and post-central gyrus between 290 and 340 ms, (c) the anterior cingulate cortex (BA 24) between 280 and 300 ms, (d) the left parieto-temporal region (BA 40) between 300 and 310 ms, and (e) the right occipito-temporal cortex (BA 19) between 270 and 300 ms.

3.2 Auditory task

Figure 4 shows the MEG waveforms for a typical subject. Figure 5 shows the regions where the significant enhancement of the neural activity was detected in the infrequent target stimulus presentation compared to the frequent stimulus presentation during the auditory task ($p < 0.0005$). Significant enhancement of the neural activity was detected in (a) the middle frontal or inferior frontal region (BA 44, 46) in the latency range between 270 and 320 ms, (b) the pre-central and post-central gyrus between 290 and 320 ms, (c) the anterior cingulate cortex (BA 24) between 280 and 310 ms, and (d) the left parieto-temporal region (BA 40) between 310 and 350 ms.

4. Discussion

Because the subject was required to respond explicitly by lifting his right index finger and the reaction times for both visual and auditory tasks were around 300 ms, motor related activities may overlap with the activities related to the infrequent target detection. In fact, the motor related activities in the pre- and post-central regions in both visual and auditory tasks were clearly separated from the other activities.

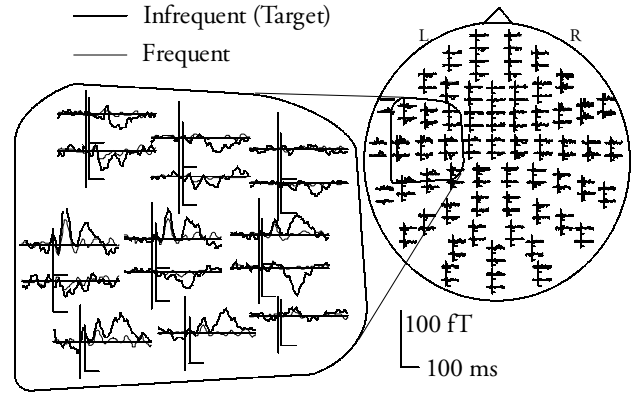
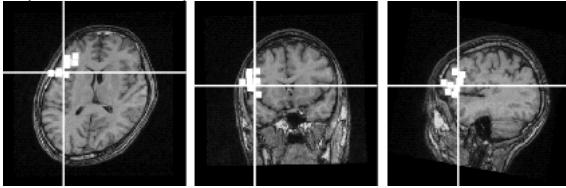
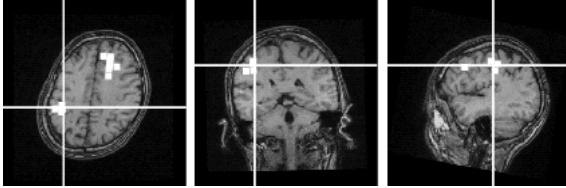


Figure 4: Example the MEG waveform measured during the auditory task.

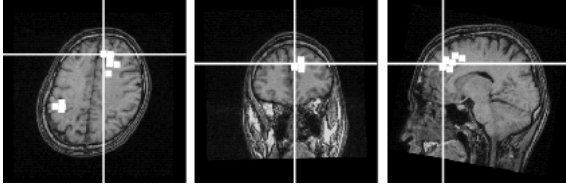
(a) Middle/inferior frontal region (BA 44,46) (t=260-310 ms)



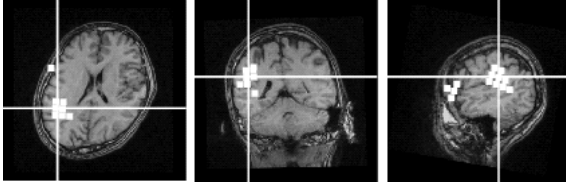
(b) Pre/post central gyrus (t=290-340 ms)



(c) Anterior cingulate cortex (BA 24) (t=280-300 ms)



(d) Left parieto-temporal region (BA 40) (t=300-310 ms)



(e) Right occipito-temporal region (BA 19) (t=270-300 ms)

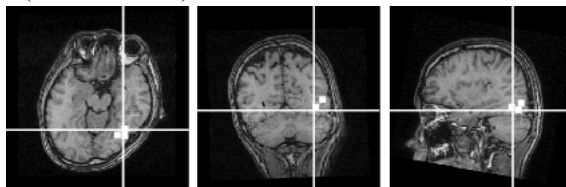
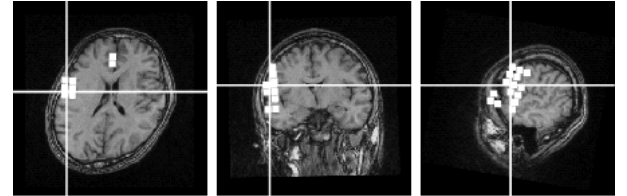
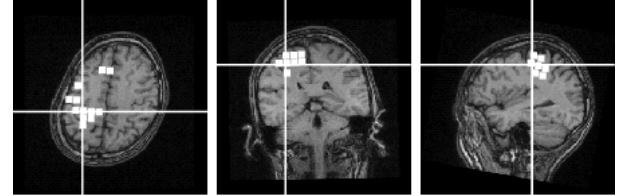


Figure 3: Distribution of the brain regions where the significant enhancement of the neural activity was detected in the infrequent target stimulus presentation compared to the frequent stimulus presentation during the visual task ($p < 0.0005$).

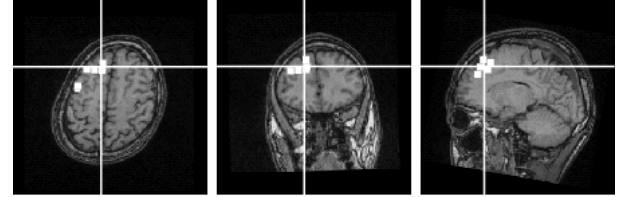
(a) Middle/inferior frontal region (BA 44,46) (t=270-320 ms)



(b) Pre/post central gyrus (t=290-320 ms)



(c) Anterior cingulate cortex (BA 24) (t=280-310 ms)



(d) Left parieto-temporal region (BA 40) (t=310-350 ms)

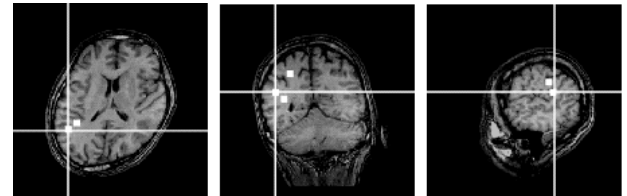


Figure 5: Distribution of the brain regions where the significant enhancement of the neural activity was detected in the infrequent target stimulus presentation compared to the frequent stimulus presentation during the auditory task ($p < 0.0005$).

Recent neuroimaging studies have suggested that there were multiple modality-specific and modality-independent regions involved in the infrequent target detection operations [5-7]. The present results indicated the modality-independent activation in the left middle/inferior frontal region, the anterior cingulate cortex, and the left parieto-temporal region related to the infrequent target detection. These results partly agree with the recent fMRI studies [5-7] in terms of their locations, however, activities in the middle frontal region and the supramarginal region were reported to be observed bilaterally in the previous fMRI studies. These discrepancies may be due to the differences of the spatial and/or temporal resolutions and the detectable physiological signal characteristics between the neuromagnetic and the hemodynamic measurements. In particular, present neuromagnetic results extracted the multiple neural activities in the latency range between 250 and 350 ms after the target stimulus onset, while the previous hemodynamic results have dealt with the sustained activities related to the target detection operations in the brain.

The activities in the parieto-temporal region are in agreement with the studies showing that lesion to the temporal-parietal cortex abolish the scalp P3b component measured by EEG [10], and that intracranial P3 signals have recorded in this region [11]. This region is known to receive pre-processed information from multiple modality-specific areas, including vision and audition, and thus thought to be involved in the evaluation, categorization and decision making operations based on the modality-independent information [12].

References

- [1] S. Sutton, M. Braren, and J. Zubin, "Evoked-potential correlates of stimulus uncertainty", *Science* **150**, 1187-1188, 1965.
- [2] T.W. Picton, "The P300 wave of the human event-related potential", *J. Clin. Neurophysiol.* **9**, 456-479, 1992.
- [3] A. Baddeley, "Working memory", *Science*, **255**, 556-559, 1992.
- [4] E. Donchin and M.G.H. Coles, "Is the P300 component a manifest of context updating?", *Behav. Brain Sci.* **11**: 357-374, 1988.
- [5] G. McCarthy, M. Luby, J. Gore, and P. Goldman-Rakic, "Infrequent event transiently active human prefrontal and parietal cortex as measured by functional MRI", *J. Neurophysiol.* **77**, 1630-1634, 1997.
- [6] V. Menon, J.M. Ford, K.O. Lim, G.H. Glover, and A. Pfefferbaum, "Combined event-related fMRI and EEG evidence for temporal-parietal cortex activation during target detection", *Neuroreport* **8**, 3029-3037, 1997.
- [7] T. Yoshiura, J. Zhong, D.K. Shibata, W.E. Kwok, D.A. Shrier, and Y. Numaguchi, "Functional MRI study of auditory and visual oddball tasks", *Neuroreport* **10**, 1683-1688, 1999.
- [8] O.L. Frost, "An algorithm for linearly constrained adaptive array processing", *Proc. IEEE* **60**, 926-935, 1972.
- [9] B.D. Van Veen, W. van Drongelen, M. Yuchtman, and A. Suzuki, "Localization of brain electrical activity via linearly constrained minimum variance spatial filtering", *IEEE Trans. Biomed. Eng.* **44**, 867-880, 1997.
- [10] R.T. Knight, D. Scabini, D.L. Woods, and C.C. Clayworth, "Contributions of temporal-parietal junction to the human auditory P3", *Brain Res.* **502**, 109-116, 1989.
- [11] E. Halgren, P. Baudena, J.M. Clarke, G. Heit, C. Liegeois, P. Chauvel, and A. Musolino, "Intra-cerebral potentials to rare target and distractor auditory and visual stimuli. I. Superior temporal plane and parietal lobe", *Electroenceph. clin. Neurophysiol.* **94**, 191-220, 1995.
- [12] M.M. Mesulam, "Large-scale neurocognitive networks and distributed processing for attention, language, and memory", *Ann. Neurol.* **28**, 597-613, 1990.